CHAPTER

TYPES AND STRUCTURE

1

A turnout is a trackside installation enabling railway vehicles to change tracks or crossover another track. It is an essential part of a railway track system. In fact, a turnout is an integrated system. It is difficult to maintain and critical to riding speed and safety. In addition, it is regarded as the weak point of a line and a main concern in high-speed railway (HSR) construction [1,2].

1.1 MAIN TYPES [3]

High-speed turnouts refer to the turnouts for 250 km/h and above in the main line. Among these turnouts, those for 160 km/h and above in the diverging line are known as high-speed turnouts in the diverging line, which have greater numbers and longer lengths than other turnouts.

1.1.1 COMPOSITION

A high-speed turnout is composed of rails, sub-rail foundations (e.g., fastenings, ties, and ballast or ballastless bed), conversion equipment, monitoring system, turnout heaters, and track stiffness transitions at two ends [4].

It is generally designed as a simple type crossing owing to the structural complexity, that is, consisting of a set of switches, crossing, and transition lead curve.

1.1.2 CLASSIFICATION

Main types:

1. Turnouts for 250 km/h and 350 km/h in the main line.
2. Turnouts for 80 km/h, 120 km/h, 160 km/h, and 220 km/h in the diverging line.
3. Turnouts in the main line, the crossover, and the connecting line (by function). The turnout in the main line lies at the throat of a station, enabling trains to access the receiving-departure track through the main line. The turnout in the crossover, as shown in Figure 1.1, lies away from the station throat and enables a train to switch routes between the up line and the down line. The turnout in the connecting line also lies outside the station throat and enables a train to change tracks between two HSR lines. The three types of turnouts are for 80 km/h, 80−160 km/h, and 120−220 km/h in the diverging line, respectively.

Design of High-Speed Railway Turnouts.

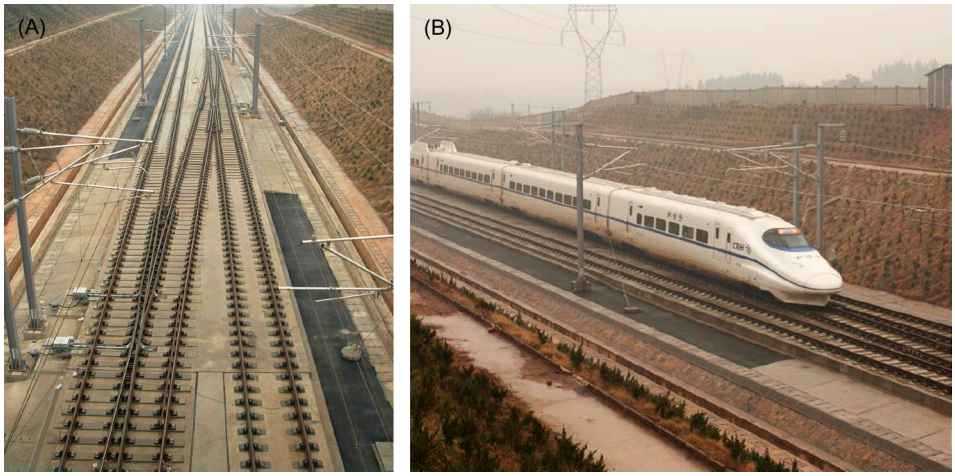

FIGURE 1.1

(A) Layout of crossover turnouts. (B) An EMU train changing tracks between the up line and the down line.

4. Ballasted turnouts and ballastless turnouts (by subfoundations). Ballasted turnout uses prestressed concrete ties; ballastless one may use embedded concrete ties or slabs. The two turnouts use the same rails.
5. No. 18, No. 30, No. 42, and No. 62 turnouts, etc. (by turnout number). In France and Germany, a high-speed turnout in the diverging line may have a nonintegral number (e.g., No. 39.113) when being laid in a line with varied track distances.
6. Turnouts with swing nose crossings or fixed crossings (by crossing type). All high-speed turnouts in China are provided with swing nose crossings, whereas in other countries, fixed crossings may be used in some turnouts for 250 km/h.
7. Turnouts with a rail cant of 1:40 or 1:20 (by rail cant). The rail cant of high-speed turnouts is 1:40 in both China and Germany, and 1:20 in France.
8. In addition, 60 kg/m rails, standard gauge, and trans-sectional continuously welded rail (CWR) track are quite common in HSRs, so high-speed turnouts are not classified by rail type, gauge, or joint.

Normally, a high-speed turnout is named after the combination of the rail type, the permissible speed in the main line, the sub-rail foundation, and the turnout number, such as No. 18 ballastless simple turnout with 60 kg/m rails for 350 km/h.

1.2 TECHNICAL REQUIREMENTS

A high-speed turnout is an intricate system. It involves the technologies of track structures (rails, fasteners, ties, and ballasted and ballastless bed, etc.), interface technologies of CWR track on embankments and bridges, the wheel–rail relation, electrical conversion, and track circuit, as well as interdisciplinary technologies of precision machinery manufacturing, mechanized track laying and maintenance, control survey, and informatized management [5].

1.2.1 EXCELLENT TECHNICAL PERFORMANCE

A high-speed turnout shall meet the following technical requirements:

1. High speed

   It shall have the same speed in the main line of the turnout as in a common railway section, and have a relatively high speed in the diverging line without affecting normal traffic. For safety considerations, the design speeds in the main line and the diverging line shall have safety margins of 10% and 10 km/h, respectively.
2. High safety

   For a high-speed turnout, the following requirements shall be satisfied when an Electric Multiple Unit (EMU) train travels at the design speed in the main/diverging line:
   - **a.** Indicators such as load reduction rate and derailment coefficient are the same as in a section
   - **b.** The spreads of switch rails and swing nose rails are sufficient to avoid collision against wheels
   - **c.** The conversion equipment functions normally, so that no defective insulation area (where all traffic lights are red) or signal abnormalities occur
   - **d.** Moveable rails are locked securely, so that no derailment takes place in case any inclusion appears in the closed zones, or the switch rod is distorted by the inclusion
   - **e.** The monitoring systems are integrated to identify faults and hidden dangers degrading riding safety, such as abnormal conversion, inordinate closure, and rail fracture; and
   - **f.** Turnout heaters are provided in cold areas to prevent snow or ice accumulating at the switches and crossings in cold weather, so as to ensure normal operation.
3. High stability

   When an EMU train travels at a normal speed in the main/diverging line of turnouts, the train will not shake significantly, thus providing the same passenger comfort in turnouts as in sections. The lateral carbody acceleration shall not have first-order inordinateness (i.e., 0.6 m/s^2 as per the criteria of the planned preventive maintenance for Chinese HSR) during the passage of comprehensive inspection trains or track geometry cars in the turnout.
4. Excellent comfort

   The same passenger comfort can be offered vertically as in a section, and no "jerking" (which may occur at bridge ends) occurs when an EMU train travels at a normal speed in the main/diverging line, nor does any inordinate vertical vibration appear due to inhomogeneous track integral stiffness in the turnout area. The vertical carbody acceleration shall not have first-order inordinateness (i.e., 1.0 m/s^2 as per the criteria of the planned preventive maintenance for Chinese HSR) during the passage of comprehensive inspection trains or track geometry cars in the turnout.
5. High reliability

   HSRs are in closed operation in the daytime, and occupied for "skylight" maintenance at nighttime. Therefore, high-speed turnouts shall have high reliability, without conversion faults or invalid closure detections, etc.
6. High smoothness

   All HSR track structures, including high-speed turnouts, shall have high performance in smoothness. Geometric deviation (alignment, longitudinal level, etc.) and closure clearances of a turnout shall be acceptable. The scant switching displacement shall not affect the deviation of the gauge, and structural irregularities induced by wheel–rail relation shall not affect riding quality.

7. High accuracy

   A turnout is composed of thousands of components; each component may have certain manufacturing errors. For high smoothness in assembly geometry and closure, the manufacture, assembly, and laying must be highly accurate (optimally 0.2 mm as per the criteria for planned preventive maintenance for Chinese HSRs).
8. High stability and less maintenance

   A high margin of strength is required under the action of high-speed trains and temperature, etc., so that turnouts are less susceptible to large residual deformation, featuring higher structural stability and less maintenance.
9. Easy maintenance

   With the increase in operation time, gross carrying tonnage, and deterioration of turnouts, tracks with inordinate irregularities or seriously damaged components shall be repaired or replaced immediately during the "skylight" period to resume normal operation in the shortest possible time. The structural design of high-speed turnouts shall facilitate future maintenance from practical and technical considerations.

1.2.2 HIGH COST-EFFECTIVENESS

The rails (switch rail, point rail, etc.) of a turnout will bear great wheel−rail force when guiding the wheels during conversion operations. Therefore, they are subject to wear or damage due to thin cross sections, resulting in short service life and frequent replacement. High-speed turnouts are used extensively. Generally for HSRs, one station shall be set every 30 km, and each station shall have at least 4−8 sets of high-speed turnouts. Therefore, to cut down the maintenance cost, high-speed turnouts shall be highly cost-effective.

1.2.3 OUTSTANDING ADAPTABILITY

High-speed turnouts may be laid on ballasted tracks, ballastless tracks with different geological conditions, or in cold regions, so they shall preferably agree with the climate and environment. In China, HSRs are mainly built on bridges rather than embankments. As there are lots of bridges, elevated stations are necessary. So turnouts may be laid on bridges, and certain stations may also lie in tunnels. This calls for adaptability of turnouts to different foundations.

1.3 TECHNICAL FEATURES [6]

1.3.1 SYSTEM INTEGRATION

High-speed turnouts have two major parts: engineering facilities (rails, fastenings, turnout ties, and sub-rail foundation) and electrical facilities (e.g., conversion system, monitoring system, and turnout heaters). Both are essential for operation and high technical performances of the turnouts. They must be high-precision electromechanical devices rather than simple civil structures.

In addition, high-speed turnouts integrate the latest technologies in track structures (e.g., rails and fastenings, ballastless tracks, and CWRs), and combine recent research achievements in design,

manufacture, transport, laying, and maintenance. Therefore, they mark the state of the art of high-speed track structures of a country to some extent.

1.3.2 THEORETICAL BASIS AND PRACTICAL TESTS

As the key equipment in terms of riding safety and quality of high-speed trains, high-speed turnouts shall be designed in line with the theories of wheel–rail relations, track stiffness, CWR lines, etc. Turnouts can be accepted for production and application only upon passing the stepwise speed-up dynamic tests with real cars and long-term running tests.

1.3.3 STATE-OF-THE-ART MANUFACTURE AND LAYING PROCESSES

For high technical performance, high-speed turnouts shall be manufactured with modern equipment (e.g., long and large CNC planer-type milling machines, high-precision CNC saw drills, large-tonnage press, advanced rail welding machines, large-scale hoisting machines, and high-precision assembly platforms), technologies, and detection equipment. Additionally, the concept "detail is everything" shall be borne in mind, and a strict quality management system for raw materials, purchased components, and production processes shall be formulated, thus forming a factory-centered integrated supply and resident supervision system.

Laying is a key process for ensuring high technical performance. Successful laying means that the permissible speed can be reached immediately after the high-speed turnouts are put into use. So mechanical, standard construction processes and professional construction teams are required.

1.3.4 SCIENTIFIC MAINTENANCE AND MANAGEMENT

HSRs are in closed operation in the daytime, inspected and maintained only during the "skylight" period at nighttime. Therefore, for high technical performance, less maintenance, and orderly operation of turnouts, informatized and scientific maintenance methods are required, and reliability-oriented modern maintenance facilities shall be developed for high-speed turnouts.

1.4 GLOBAL OVERVIEW OF HIGH-SPEED TURNOUTS

1.4.1 FRANCE

Cogifer has become the most intimate partner of SNCF since 1975. In 1981, the first generation of high-speed turnouts with timber ties was designed and manufactured. Meanwhile, single cubic parabola curve type No. 46 and No. 65 high-speed turnouts in the diverging line for 270 km/h were also developed. The second generation changed the single parabola curve to a "circular + easement" curve and adopted concrete ties and ballasted beds, creating a world speed record of 501 km/h in the main line in 1990. At present, the third generation is widely used in railways from Paris to Marseilles for up to 300 km/h. The fourth generation adopts NiCr antifriction coatings and adjustable rollers based on the third generation, which will be used in new railways for more than 330 km/h (Figure 1.2). After numerous tests, the technology of French high-speed turnouts has been

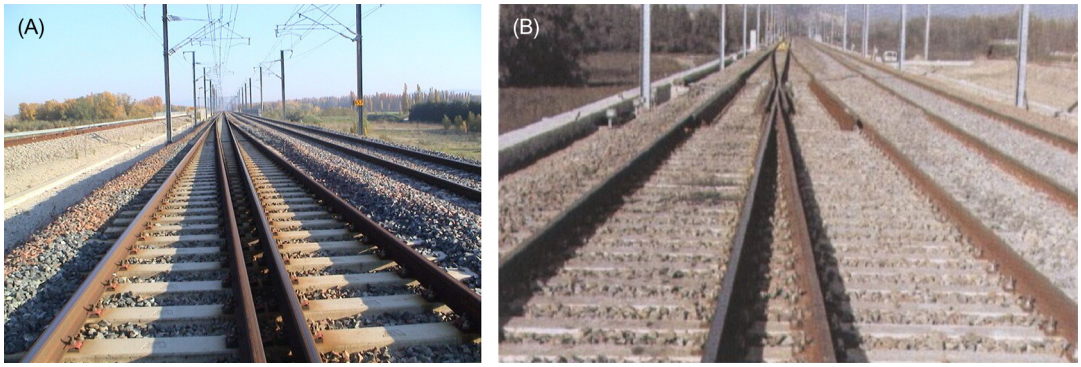

FIGURE 1.2

High-speed turnout in France: (A) Switch; (B) Crossing.

improved drastically. About 1200 sets of Cogifer high-speed turnouts have been used in railways around the world, of which more than 200 are used in Chinese railway lines (Zhengzhou−Xi'an, Hefei−Nanjing, and Hefei−Wuhan) [7,8].

1. Plane line type

   High-speed turnouts in France include No. 65, No. 46, No. 29, No. 26, No. 21, and No. 15.3 series, for 230 km/h, 170 km/h, 160 km/h, 130 km/h, 100 km/h, and 80 km/h in the diverging line, respectively. Normally, the "circular + easement" curve line type is adopted for high-speed turnouts in the diverging line, and circular curve for the rest.

   Design controlling indexes:

   If $V_{\text{diverging}} = 70-170$ km/h: the unbalanced centrifugal acceleration $\alpha \leq 0.65\ m/s^2$, the deficient superelevation ≤ 100 mm, and the variation rate of deficient superelevation ≤ 236 mm/s; or

   If $V_{\text{diverging}} = 170-230$ km/h: the unbalanced centrifugal acceleration $\alpha \leq 0.56\ m/s^2$, the maximum deficient superelevation ≤ 85 mm, and the variation rate of deficient superelevation ≤ 260 mm/s.

2. Switch

   In France, switch rails are made of monoblock flat-web-special section rails (AT rails in China), and mainly are untempered UIC60D rails (strength: 900 A). To reduce the expansion displacement of the switch rails of CWR turnouts, the following considerations shall apply: (a) the longitudinal resistance of turnout fasteners shall not be below track resistance; (b) the fastening force of a set of fasteners shall be greater than 12 kN; (c) the switch rail shall have the smallest movable length; and (d) modified Nabla fasteners (Figure 1.3A) or USK2/SKL24 clips of Vossloh (Figure 1.3B) shall be used at the narrow heel end of the switch rail.

   In France, the conversion of switch rails relies on the rolling friction, rather than sliding friction, with the provision of lubrication-free or rollered slide plates (Figure 1.4). Thus, it reduces switching resistance, scant displacement, and switching force; increases traction points; shortens the distance between the last traction point and the heel of the switch rail; and maintains the line type of switch rails by the connecting rods in between.

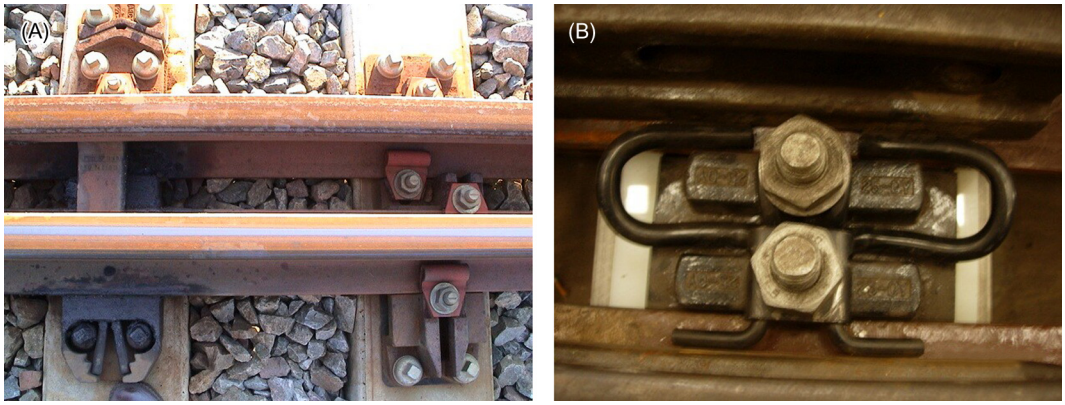

FIGURE 1.3

Compromise fasteners at the heel of the switch rail: (A) Nabla compromise fasteners; (B) Vossloh compromise fasteners.

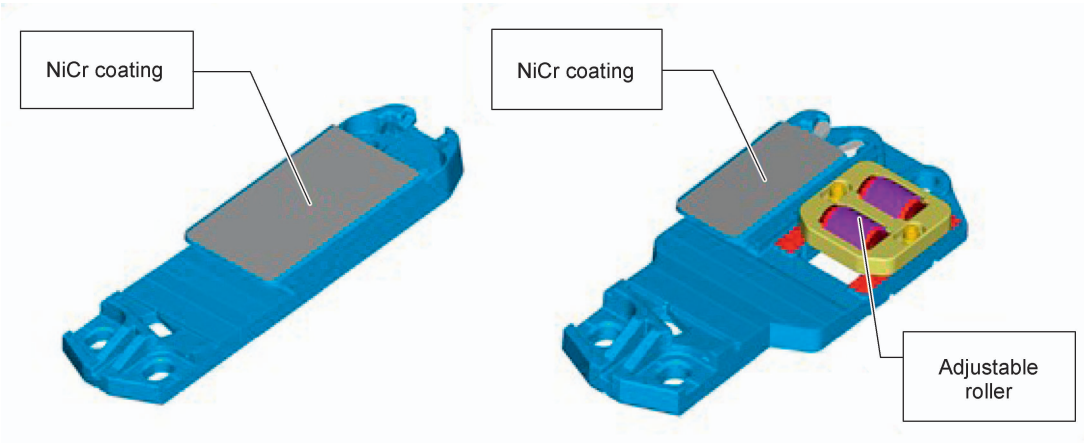

FIGURE 1.4

Antifriction slide plate.

French high-speed turnouts are fixed by approximately n-shaped elastic clips (Figure 1.5), whose fastening force is equivalent to that of ordinary fasteners. These clips can fix the inner side of stock rails reliably to prevent rail tilting. They are easy to handle with special tools.

In France, based on the relationship among the degree of hunting movement of trains, the cant at rail base and the critical speed, it is proposed according to wheelset dynamics that the rail cant of 1:20 is preferable for high-speed turnouts for more than 250 km/h. In this way, the design equivalent conicity of treads and the maximum equivalent conicity of the worn profile can be controlled within 0.1 and 0.15, respectively.

FIGURE 1.5

Elastic clips for French turnouts.

FIGURE 1.6

Horizontal hidden tip point structure of the point rail.

3. Crossing

In France, point rails and switch rails are made of the same materials. The point rails are constructed by embedding and assembling the long and short point rails with Huck bolts (in factory) or high-strength bolts (on site). To reduce lateral irregularity during passage at the crossing, a horizontal hidden tip point structure is adopted for the point rail, as shown in Figure 1.6.

Long fillers are set at the crossing heel. Specifically, three fillers are arranged on each side of the point rails and the wing rails and coupled with elastic sleeve-type locking bolts (Figure 1.7). The longitudinal forces distributed on the bolts of long rails in turnout rear are approximately the same, and can be transmitted to the rails in the transition lead curve through long wing rails.

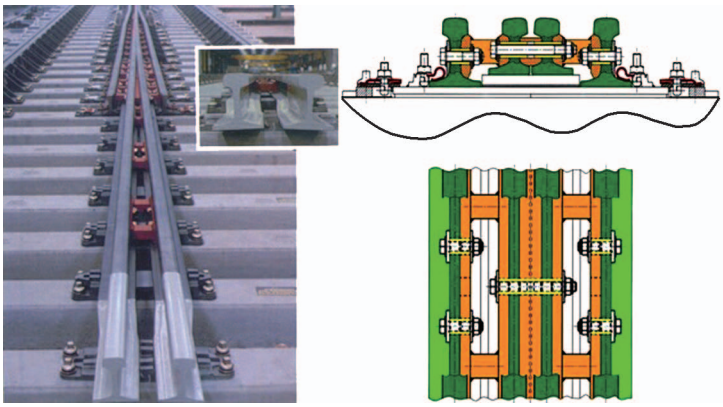

FIGURE 1.7

Crossing heel structure.

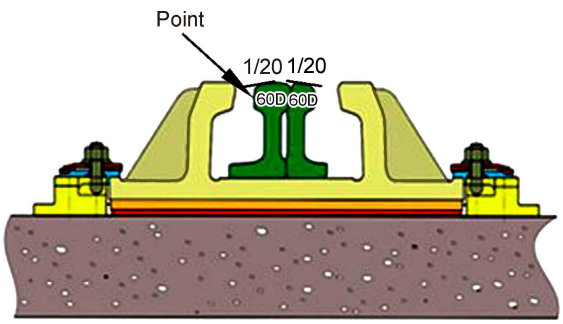

FIGURE 1.8

Solid "cradle-type" crossing.

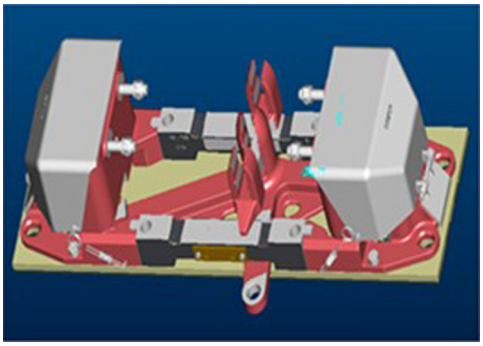

FIGURE 1.9

Bracket of the point rail.

The wing rails of French high-speed turnouts are of a "cradle" structure (monoblock wing rails, with point rail laid in between), made of solid high manganese steel, as shown in Figure 1.8. The front end is welded with common rails in the factory by flash welding, and the rear end is welded with A74 rails. This structure is stable, and the point rails and wing rails will not tilt. The electrical device at the first traction point on the point rail pokes out from the bottom to pull the point rail. Three U-shaped brackets for receiving the point rails are provided, which can slide on the slide bed (Figure 1.9), allowing greater expansion displacement of the point rails. The traction point on the point rail is relatively high, so the rail is unlikely to tilt.

4. Fastenings

French high-speed turnouts are mainly fastened with Nabla clips, the same as in sections. The gauge of a turnout may vary slightly owing to slight abrasion of rails in use, so it is nonadjustable.

FIGURE 1.10

Fastenings of ballasted turnout.

The ballasted turnouts in China designed by Cogifer adopt SKl-12 narrow clips of Vossloh, provided with a 9 mm rubber pad under the rail and a 4 mm rubber pad under the tie plate. At the slide bed, only a 9 mm rubber pad is provided beneath the plate (no rail pad). In the non-breathing length of the heel, both the rail and the plate are provided with a 4.5 mm rubber pad underneath. The tie plate is connected to the tie by double-row Φ24 high-strength bolts. A riser block may be arranged under the plate, with vertical adjustment capacity of 0−10 mm. A gauge block is not arranged. The track gauge is regulated by a quadrant block at the end of the tie plate with an adjustment range of −4 to +2 mm, as shown in Figure 1.10.

The ballastless turnouts in China designed by Cogifer adopt W300 fastenings and SKl-15 clips of Vossloh, provided with a 6 mm rubber pad under the rail and a 12 mm elastic pad under the plate. The cast iron shoulder cooperates with the V-shaped groove on the tie, and the stress point of the anchor bolts is relatively low. The riser block, with a vertical adjustment range of −4 to +26 mm, is installed under the plate. The insulated gauge block can adjust the gauge in collaboration with the spacer, with an adjustment range of −4 to +8 mm, as shown in Figure 1.11.

Unlike other countries, the ballasted turnouts in France are characterized by high stiffness of fastening and low stiffness in the bed. The pad stiffness of a turnout is determined as per the principle that the vertical displacement of the tie and the rail can be controlled within 0.5−0.7 mm and 1 mm, respectively. The turnout bed is made of uniformly graded premium granite ballasts (Figure 1.12), whose elasticity equals the tie support stiffness of 40−60 kN/mm. The static pad stiffness at the switch and the crossing is 200−250 kN/mm. The transition of track stiffness between a turnout and a section is about 5 m long, so the vertical displacement of the rail under static wheel load is 0.9 mm (Figure 1.13).

The stiffness setting of turnout fastenings in France has many advantages. It can control the displacement of switch rails and swing nose rails with respect to stock rails and wing rails, reduce rail stress, control the dynamic gauge widening in a turnout, and decrease the loss of fastening force of the fasteners. However, it is disadvantageous in the overlarge stiffness of the